National Data Buoy Center 1.8-meter Discus Buoy, Directional Wave System

Chung-Chu Teng[1], Theodore Mettlach[2], Joel Chaffin[2], Robert Bass[2], Charles Bond[2], Charles Carpenter[2], Richard Dinoso[2], Mark Hellenschmidt[2] and Landry Bernard[2]

[1]National Data Buoy Center
Building 1100
Stennis Space Center, MS 39529 USA

[2]Science Applications International Corporation
Building 3205
Stennis Space Center, MS 39529 USA

***Abstract*-Since year 2005, the National Data Buoy Center (NDBC) has been developing, testing, evaluating and refining a pitch-roll-heave directional wave measuring system. It consists of a 1.8-meter-diameter isomer foam flotation ring in the center of which is placed a cylindrical battery and instrument compartment. A MicroStrain® 3DM-GX1 motion sensor, located at the center of flotation, provides a stream of nine measurements subsampled at a rate of 2,048 samples in 1,200 seconds. The buoy transmits standard NDBC directional wave spectral information each hour via an Iridium® satellite modem after computing directional wave spectra from triaxial components of earth magnetic flux density and angular rate, and along-mast acceleration. Additionally, high-resolution data are stored onboard the station for post-deployment analysis. Testing has been done in seven steps. First, static testing of the 3DM-GX1 revealed that the measurement mode of the sensor yields varying amounts of electronic and processor noise. The best mode and time constants for the sensor were determined in the second step of development, using a desktop wave simulator designed exclusively for that purpose. It provided precisely known simulated directional wave information. In the third step, the complete buoy payload, including an air-depolarized, alkaline battery pack manufactured by Cegasa International was placed on the one-meter radius NDBC directional wave simulator, with which a full end-to-end test was conducted. Fourth, after sufficient laboratory testing, the complete system was deployed near NDBC station 42007 in the northern Gulf of Mexico for several days, and there was found close agreement between measurements from the two platforms. Additional, as a fifth step, a second 1.8-m buoy with a different battery pack, consisting of 700 alkaline D-cells, was evaluated and found to be adequate, yet the batteries interfered with magnetometer measurements more than the smaller, lighter Cegasa® battery pack. In the sixth step, the buoy with Cegasa batteries was deployed in shallow water at the U.S. Army Corps of Engineers Field Research Facility, Duck, North Carolina, from December 2006 until April 2007. This deployment provided two sources of accurate directional wave data as a basis for comparison, the FRF 8-meter array of bottom-mounted pressure sensors and a Datawell Waverider® buoy. Comparisons indicated that the 1.8-m buoy gives excellent non-directional wave spectra and accurate wave directions. A small drawback, an area of on-going research, is that the buoy gives lower than desired spreading function values. It produces characteristically lower values than does the lighter, particle-following Waverider buoy. Finally, NDBC deployed an identical, second 1.8-meter buoy off Mission Bay, California, next to another Datawell Waverider, from February to June 2007. Directional wave accuracy, using swell waves from a distant storm as ground truth, has proven to be excellent, although, as with the first deployment at Duck, directional spreading is less than desired. We speculate this is due to size and shape of hull and limitations arising from pitch-roll signal -to-noise ratio.**

I. Introduction

For nearly 30 years, the National Data Buoy Center (NDBC) has remained actively involved in developing techniques for acquiring directional wave measurements from moored buoys. The latest development has been incorporation of the MicroStrain® 3DM-GX1 gyro-enhanced orientation sensor in the NDBC wave and meteorological data acquisition system (WAMDAS) payload, installed on a 1.8-meter discus buoy. In readying a 1.8-meter buoy for field deployment at Cook Inlet, Alaska, NDBC conducted a series of laboratory and field tests in 2006 and 2007, allowing us to characterize the accuracy of this new hull-payload-sensor configuration as a wave measurement system. The small size of the 3DM-GX1 has permitted careful testing using an inexpensive desktop wave simulator, designed, fabricated and tested by SAIC Senior Electrical Engineer Joel Chaffin. The smaller-than-usual battery pack also permitted full use of the NDBC operational wave instrument facility (OWIF) for both pre- and post calibration. Field test strategy has been to step from the northern Gulf of Mexico to verify functionality, to the U.S. Army Corps of Engineers, Field Research Facility at Duck, North Carolina, to compare buoy wave measurements to simultaneous ones from a Datawell Waverider®, to the California coast to examine buoy response to long-period swell waves. This paper documents performance of the 1.8-m buoy with WAMDAS, discusses unfinished work and argues that further, incremental refinement of NDBC pitch-roll-heave buoys is hull- and mooring-dependent.

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Wave Measurements

A directional wave spectrum $S(f,\theta)$ of the following form, a function of frequency *f* and wave direction θ, is sought:

$$S(f,\theta)=C_{11}(f)D(f,\theta)\,. \tag{1}$$

$C_{11}(f)$ is the non-directional sea surface displacement spectrum. After [1], we write the spreading function $D(f,\theta)$ as a Fourier series:

$$D(f,\theta)=\frac{\left\{\frac{1}{2}+\sum_{1}^{\infty} r_n\cos\left[n\left(\theta-\theta_n\right)\right]\right\}}{\pi}\,. \tag{2}$$

However, without sea surface curvature and higher order dynamics, only the first two terms of the series are used. Thus,

$$D(f,\theta)\cong\frac{\left\{\frac{1}{2}+r_1\cos\left[\theta-\theta_1\right]+r_2\cos\left[2(\theta-\theta_2)\right]\right\}}{\pi}\,. \tag{3}$$

The frequency-dependent spreading functions r_1 and r_2 range from zero to unity, a value of one indicating that all wave energy at a particular frequency is associated with a single direction. The directions θ_1 and θ_2 in equation (3) represent the direction, counter-clockwise from east, toward which a wave travels. The former is associated with mean wave direction; the second with primary wave direction. Complete description of NDBC buoy measurements is given in references [2] through [5].

Using a mast-aligned accelerometer, as is used in the 1.8-m buoy, the non-directional, displacement spectrum $C_{11}(f)$ is obtained from the energy spectrum of accelerations, corrected by function *NC*, a heave-hull transfer function R^{hH} and a conversion function to go from acceleration to displacement. We write it as follows:

$$C_{11}(f)=\frac{C_{11}^{m}(f)-NC}{\left(2\pi\cdot f\right)^4(R^{hH})^2}\,.$$

For the 1.8-m hull, the R^{hH} is near unity for all frequencies below about .5 hertz. We have yet to exactly determine this function, although data collected from field tests will soon make this possible.

Fig. 1 CLOS5 moored near Field Research Facility, Duck, North Caroline, December 2006. (image courtesy NOAA)

Buoy Description

Fig. 1 shows an NDBC 1.8-meter buoy. It has a cylindrical central compartment surrounded by a flotation collar made from Gilman isomer foam. Lifting eyes on deck enable easy deployment from a ship's winch. A rounded chine on the outer edge of the underside reduces the impact of waves slapping against the freeboard. A chain mooring is attached to a four-strut, stainless steel bridle on the underside, extending 1.4-m below the water line. A thermoplastic dome on top houses an operation and indicator light, powered by a small solar panel. Above the dome is a mast assembly holding a radar reflector and two check valves, allowing fresh air to enter the battery compartment. Air is necessary to keep the Cegasa® air-depolarized batteries functioning. The buoy hull resonates in pitch and roll at 0.7 seconds and in heave at one second.

II. Static Tests

Prior to deployment, we conducted static testing of the 3DM-GX1, acquiring and then spectrally analyzing time series of vertical acceleration. Spectra from three tests are shown in Fig. 2, where it becomes obvious that the MicroStrain *gyro-stabilized* mode of data acquisition contains less noise than the *instantaneous* mode. The former uses a complementary filter in tracking orientation, therefore noise peaks at the lowest frequency and gradually declines in the fashion of an inverse power function. This testing provided basis for using *gyro-stabilized* mode for wave data acquisition and to examine using a noise correction *NC* of the 1/*f* form, rather than a linear function, as has been employed since the 1980s [6].

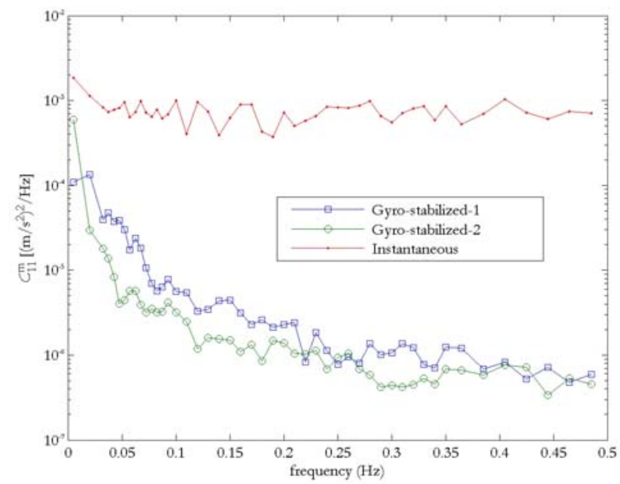

Fig. 2 Static Tests. Acceleration spectra from three static tests of the 3DM-GX1. The vertical axis is the auto-spectrum of vertical acceleration from the sensor.

Fig. 3 On the table to the right is the DTWS, set up to simulate a wave coming from 090 degrees N., from background to foreground. On the left is the WAMDAS, with one cable going to the Iridium® antenna, a second connected to a laptop computer and a third to the power supply. On the upper rotating arm of the DTWS is seen the MicroStrain 3DM-GX1. (image courtesy NOAA)

III. Desktop Wave Simulator Tests

Chaffin's desktop wave simulator, seen in Fig. 3, is a small Ferris wheel device that simulates the orbit of a point on the undulating sea surface in deep water. It consists of a rotating bar, the ends of which trace out a circle. At the end of one arm, the upper one in the picture, there is a small platform onto which the 3DM-GX1 can be affixed. The end of the other arm has a counterweight. A second drive belt rocks the center point of bar rotation back and forth, making the platform tilt up in the direction to which it swings up in its orbit and to tilt down as it moves down in its orbit. In the photo, the 3DM-GX1 is tilting up as it swings up. The direction in which the device is aligned simulates wave direction. Amplitude of orbit a = .195 meters, so any significant wave height measured with the DTWS should be $H_{mo} = 2a\sqrt{2} = .55$ meters. Wave period is obtained by using a stopwatch. The WAMDAS-3DM-GX1 was connected to an Iridium® transmitter and an external power supply at the compass rose of NDBC's Dr. Ed Michelena Test Facility. This is an area of uniform magnetic flux density, mostly from the earth's field. Direction is known.

Two tests were used: (1) Wave coming from 000 degrees N., buoy heading 270 degrees N; (2) Wave coming from 090 degrees N, buoy heading 000 degrees N. For both cases, the wave period was 3.45 seconds.

Table I gives the input parameters for two DTWS tests. Slight imperfections in the design of the DTWS explain the differences in expected and measured wave parameters. The tests was done mostly to confirm that all sign and direction conventions in wave processing software, in the 3DM-GX1 and in NDBC shore side processing routines had been properly followed. The 9- and 13-degree differences in what we thought would be the wave direction from the DTWS and what was computed was due to slight misalignments in the DTWS.

TABLE I
RESULTS OF END-TO-END TESTING OF WAVE AND METEOROLOGICAL DATA ACQUISITION SYSTEM AT DR. ED MICHELENA TEST FACILITY

Parameter		Significant wave height H_{M0} (meters)	Mean wave direction θ_P (degrees North.)	Peak wave period (seconds)	Mean buoy azimuth ± standard deviation (degrees North)
Case 1	input	.55	0	.29	≈270
	measured	.53	9.0	.29	270.86 ± 1.52
Case 2	input	.55	90	.29	≈0
	measured	.52	102.0	.29	3.67 ± 2.38

Fig. 4 NDBC Ocean Wave Instrument Facility in Building 3203, Stennis Space Center, Mississippi. (image courtesy NOAA)

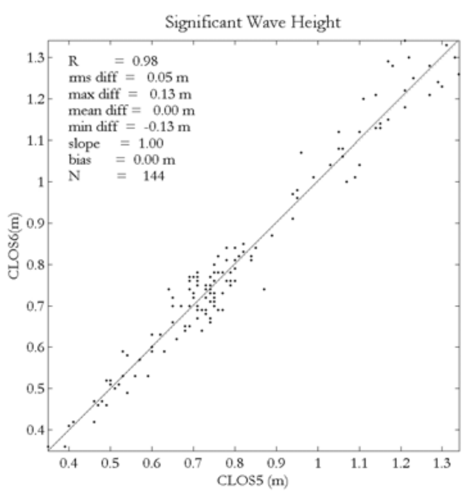

Fig. 5 Scatter diagram of contemporaneous significant wave height measurements from CLOS5 and nearby experimental buoy CLOS6 for 144 hours in November-December 2006.

IV. Ocean Wave Instrument Facility Tests

Similar to the DTWS is the much larger Ocean Wave Instrument Facility (OWIF) in the main industrial building of NDBC. The OWIF consists of a 1-m amplitude heavy aluminum arm attached to an electric motor controlled by a rheostat switch that allows wave periods of from about five to more than 40 seconds. The OWIF is ideal for simulating larger waves at long periods. In the photo of Fig. 4 is the complete WAMDAS and Cegasa battery pack, essentially everything that goes into the buoy cylindrical instrument compartment, reaching the zenith of a revolution on the OWIF. On the other end of the rotating arm is 65 pounds of counterweight. The OWIF can be set to tilt forward and backward 8 degrees every revolution; thus, wave height, period and direction can be controlled. Depending on the direction of rotation, wave direction is either 152 or 332 degrees. Amplitude of one meter gives a significant wave height of 2.83 meters. Buoy direction from the 3DM-GX1 is obtained primarily from magnetic flux density measurements, so to get proper directions using the OWIF, the large doors of the NDBC building must be opened and any large pieces of ferrous metal must be moved away.

In testing the WAMDAS end-to-end, a cable was run outside to an Iridium antenna. The OWIF was operated at various speeds over a two-day period, all high-resolution measurements; that is, all samples recorded at a rate of 1.7066 Hz were collected onto a flash card in the WAMDAS, and all processed data transmitted via Iridium through the National Weather Service Telecommunications Gateway and received at the NDBC Data Assembly Center. High-resolution data were processed using independent software and results compared to transmitted information. During this testing, we found a temperature-dependent timing error in the WAMDAS, requiring correction. The error produced a single measurement among the 2,048 collected during data acquisition that completely ruined the bulk wave parameters for that hour. Otherwise, all wave data coming from the OWIF met our expectations in terms of wave height, period, direction and directional wave spectral parameters. We note that the single component in the wave spectrum with wave energy produced a value of r_1 very near unity, which confirmed that all directional wave calculations were being computed properly.

V. Gulf of Mexico Deployment

The next step was to conduct a field test of the fully configured buoy. It was taken near NDBC station 42007, near 30°5´25´´N. 88°46´7´´W., a location 7.5 miles east of the northern tip of the northern most of the Chandeleur Islands and 12 miles south of the western tip of Horn Island in the northern Gulf. Water depth there is 14.9 m. A second 1.8-meter buoy, but with a different battery pack, was also deployed for testing in the same area. Fig. 5 gives a scatter diagram of significant wave height obtained from the two 1.8-m buoys over 144 hours, from 1800 UTC 27 November 2006 to 1700 UTC 3 December 2006. Table II summarizes statistical differences from among the three buoys during the period of the test. Mean differences are small and root-mean-square differences meet NDBC accuracy standards, noting that for two individual stations to have root-mean-square, directional accuracy of ±10°, NDBC standard, the difference of two stations must be within ±14.1°.

TABLE II
COMPARISON STATISTICS OBTAINED FROM WAVE PARAMETERS FROM THREE NDBC BUOYS 42007, CLOS5 AND CLOS6
NORTHERN GULF OF MEXICO, *N*=144 HOURS, 27 NOVEMBER TO 3 DECEMBER 2006

Station 1	Station2	Measurement	Correlation coefficient, *R*	Root-mean-square of differences, *rms*	Maximum difference, *max diff*	Mean difference, *mean diff*	Minimum difference, *min diff*
CLOS5	CLOS6	Significant wave height, H_{m0}	.98	.05 m	+.13 m	.00 m	-.13 m
42007	CLOS5		.97	.07 m	+.14 m	.00 m	-.27 m
42007	CLOS6		.97	.09 m	+.14 m	.01 m	-.25 m
CLOS5	CLOS6	Average wave period, T_{avg}	.98	.09 sec	+.25 sec	.00 sec	-.37 sec
42007	CLOS5		.98	.11 sec	+.07 sec	-.16 sec	-.47 sec
42007	CLOS6		.98	.10 sec	+.02 sec	-.16 sec	-.57 sec
CLOS5	CLOS6	Peak wave period, θ_p	.99	±11.4°	+90.00°	-1.02°	-36.00°
42007	CLOS5		.99	±10.6°	+50.72°	-0.97°	-33.05°
42007	CLOS6		.99	±12.9°	+77.48°	-1.97°	-28.05°

The purpose of the Gulf of Mexico deployment was to test the at-sea functionality of the new 1.8-m buoy and the ability to measure directional waves within NDBC accuracy standards. The short deployment largely determined the effectiveness of the buoy as seen in the values of Table II, where in the fifth column, root-mean-square wave height differences should be less than .28 m, period differences should be less than 1.4 sec and direction differences less than 14.1°. Individual stations should achieve accuracy of .2 m, 1 sec and 10°, respectively.

VI. DEPLOYMENT NEAR DUCK, NORTH CAROLINA

The U.S. Army Corps of Engineers Field Research Facility (FRF) at Duck, North Carolina, provided an ideal location for evaluating the 1.8-m buoy because of the many high-quality, well-maintained wave, oceanographic and meteorological sensors there, particularly the 8-meter array of pressure gauges and a Datawell Waverider moored 3,352 meters south of the 1.8-m buoy. FRF personnel deployed the buoy near 36° 11´44´´N. 75°42´56´´W in 17.1 meters of water using a light amphibious, re-supply, cargo vehicle. They deployed it on 14 December 2006 and recovered it on 25 April 2007, although in this paper, only wave data acquired from 14 December to 30 January are presented. High-resolution data have been recovered, and we are in the process of analyzing it.

In third column of Table III, we see that buoy measurements of wave height and period matched those from the Waverider, however, not all wave directions did. Culling data by significant wave height and period, as in the lower three rows of the table, produces better statistical agreement, from which we conclude that the Waverider and the 1.8-m buoy have different levels of sensitivity to small-amplitude waves. Preliminary analysis of the high-resolution data confirms this. We discuss the reasons later in this paper.

TABLE III
Comparison statistics from wave parameters from NDBC buoy CLOS5 and FRF Datawell Waverider buoy 3630
Duck, North Carolina, 1110 hours, 14 December 2006 to 30 January 2007

Measurement	Correlation Coefficient	Root-mean-square of differences	Maximum difference	Mean difference	Minimum difference	Number of hours
H_{m0}	.98	±.08 m	+0.28 m	-.01 m	-.27 m	1110
T_{avg}	.93	±.35 sec	+3.77 sec	.19 sec	-.47 sec	1110
θ_p	.87	±23.50°	+168.24°	.46°	-92.32°	1110
θ_p ($H_{m0} > 1$ m)	.94	±14.00°	+28.00°	-3.00°	-82.00°	294
θ_p ($H_{m0} > .25$ m and $.185 \le f \le .235$ Hz)	.99	±6.88°	+11.16°	-1.98°	-21.29°	143
θ_p ($H_{m0} > .25$ m and $.425 \le f \le .475$ Hz)	.99	±16.69°	+58.57°	6.16°	-30.31°	35

VII. DEPLOYMENT NEAR MISSION BAY, CALIFORNIA

On 21 February 2007, the United States Coast Guard, working with Scripps Institution of Oceanography, successfully deployed 1.8-meter directional wave buoy CLOS7 near position 32° 44´48´´N. 117°22´12´´W., 1,142 meters south of Coastal Data Information Program buoy, station 093. CDIP stations are operated by the Integrative Oceanography Division at the Scripps Institution of Oceanography, California. The program uses Datawell Waverider directional wave buoys. Water depth at both buoys exceeded 200 meters. Although NDBC recovered CLOS7 in June 2007, analysis of the data collected has yet to be completed. In Table IV, we see preliminary comparison statistics from CLOS7 and CDIP 093 match well within NDBC accuracy standards.

Low correlation in wave direction in the bottom row of Table IV results from clustering of wave directions, a phenomenon which tends to diminish the effectiveness of correlation analysis.

TABLE IV
Comparison statistics from wave parameters from NDBC buoy CLOS7 and CDIP Datawell Waverider buoy 093
Mission Bay, California, 210 hours, 21 February to 2 March 2007

Measurement	Correlation Coefficient	Root-mean-square of differences	Maximum difference	Mean difference	Minimum difference
H_{m0}	.96	±.12 m	.24 m	-.05 m	-.35 m
T_{avg}	.92	±.39 sec	.32 sec	.46 sec	-1.93 sec
T_{avg} ($f < .485$ Hz)	.92	±.32 sec	1.21 sec	.23 sec	-.74 sec
θ_p	.34	±10.29°	27.50°	.46°	-37.5°

Distant Storm

Reference [7] gives a method for verifying wave buoy directional accuracy using swell wave energy from distant storms, which we utilize for a case that occurred during the period of preliminary evaluation. At about 1400 UTC on 26 February, swell wave energy arrived at both buoys. Wave parameters from the two buoys leading up to the event are in Table V. The 1330 UTC entry is the best arrival time at 093, available because CDIP reports twice hourly.

TABLE V
WAVE PARAMETERS ASSOCIATED WITH ARRIVING SWELL WAVES

26 February 2007 (UTC)	T_p (sec) peak wave period		H_{m0} (m) significant wave height		θ_p (degrees N.) peak wave direction	
	CDIP	CLOS7	CDIP	CLOS7	CDIP	CLOS7
1100	7.14	6.69	1.79	1.63	290	289.5
1200	7.69	7.69	1.95	1.77	295	286.5
1300	7.69	7.14	2.05	1.82	298	283.5
1330	18.18		2.03		283	
1400	16.67	17.39	2.06	1.91	284	289.5
1500	16.67	17.39	2.13	1.96	274	273.5
1600	16.67	7.67	2.32	2.01	277	294.5
1700	16.67	14.81	2.28	2.03	290	280.5

The swell arrival time was obtained for both buoys using the ridgeline method, described in [7]. The two panels in Fig. 6 give hand drawn ridgelines. Contour colors are same for both stations. Swell generation time was approximately 0600 UTC 23 February 2007, where ridgeline intersects the *x*-axis. The swell that arrived at the buoys traveled at a speed of $C_g = g / 4\pi \cdot f \cong$ 13.5 m/sec, giving a travel distance of about 3,900 km.

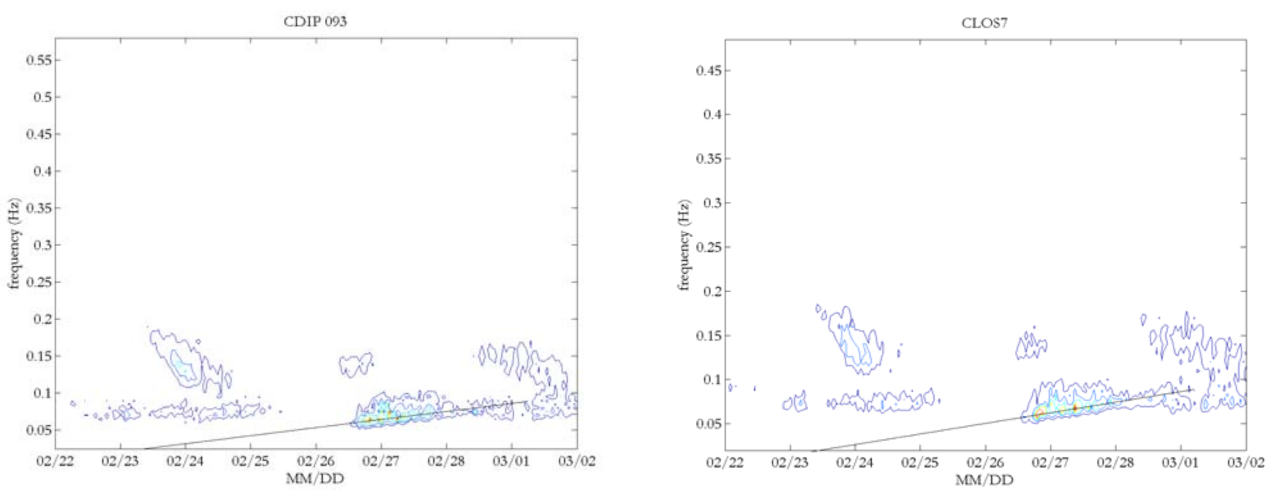

Fig. 6 Ridgeline plots over contours of spectral energy density. Colors on adjacent plots denote the same amount of spectral energy density $C_{11}(f)$. Note that the domain of the left panel exceeds that of the right panel.

The next step, obtaining swell generation location, requires back-propagating the swell wave energy from buoy to source along a great circle route in the buoy-measured direction of peak wave energy, as given in the rightmost two columns of Table V. From distance and direction, we arrive at the generation points shown in the left panel of Fig. 7, where we see that both buoys pointed to positions south of a full gale below the Aleutians. The arrows in red in the left panel of the figure denote winds in excess of 15 m/s. Wind field was obtained from National Center for Environmental Prediction/National Center for Atmospheric Research Reanalysis Project.

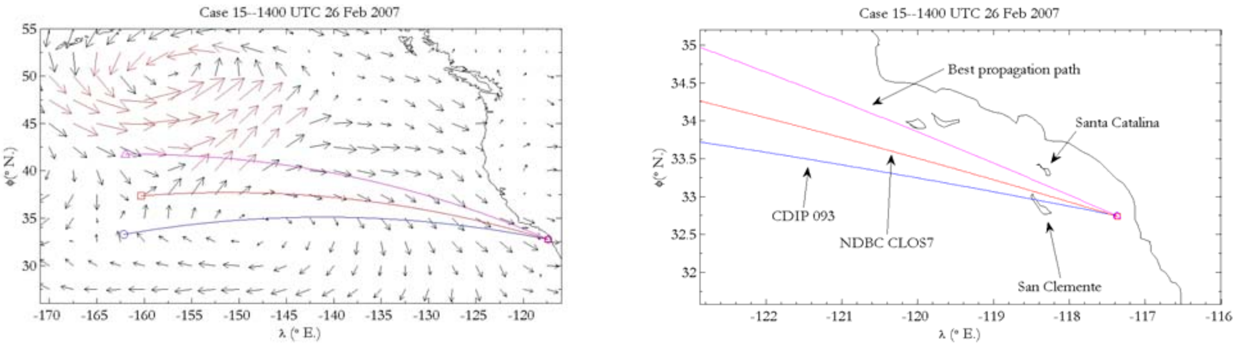

Fig. 7 Wave propagation paths inferred from buoy data and best estimate of propagation path from wind field at the time of wave generation.

Detail of the left panel of Fig. 7 is given on the right side, where we see that CLOS7 produced slightly more accurate wave direction than did 093. Although this single case is far from definitive, it goes to show that both 093 and CLOS7 provide reasonably accurate wave directions, even for relatively low amplitude swell waves from distant storms. More cases are needed, of course, to characterize fully the performance of the new NDBC 1.8-m system.

Spreading Function, r_1 and r_2

How to derive spreading functions is fully elaborated in reference [4], so we shall forego a description here. Suffice it say that high values of these functions give certain sharpness to the directional wave spectrum and a clearer picture of the state of the sea than do lower values. Not shown in this paper are the higher spreading functions from the Datawell Waverider at Duck than those from CLOS5. We see the same in Fig. 8, which confirms this characteristic of the NDBC buoy. The reason for the lower spreading function values, equivalent to smearing wave energy away from its true direction into neighboring bands is likely inherent in the pitch-roll-heave technique. Datawell originally attempted a slope-following method but soon abandoned it for particle following. As we see in Fig. 6, the sensitivity of the 1.8-m buoy to vertical energy is nearly the same as that from the Waverider, which gives us reason to consider that instrument sensitivity to small accelerations is greater than to smaller—yet physically equivalent—changes in angle, or, in the case of the 3DM-GX1, to changes in angular rate. From Fig. 7, we see that the 1.8-m buoy resolves direction adequately when there is sufficient energy; however, low values of spreading suggest that it does indeed lack sensitivity to miniscule changes in slope.

The Waverider technique appears superior to that of NDBC except in the context of survivability, reliability and general robustness. A larger, rather than a smaller, hull is required to house the large bank of batteries, required for long deployments in the hostile ocean.

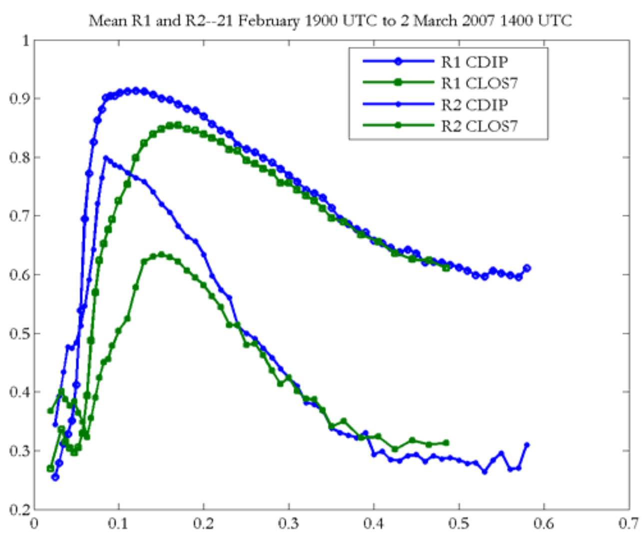

Fig. 8 Average spreading functions r_1 and r_2 from CDIP station 093 and NDBC buoy CLOS7 during period noted.

Post Calibration

After CLOS7 was recovered and returned to NDBC, the 3DM-GX1 was removed from the instrument compartment and tested on the OWIF. Frequency-dependent response to acceleration and angular rate changes were determined using 11 frequencies in which the 3DM-GX1 was positioned in three different orientations; that is, with the *x*-axis pointing forward, sideways and up. Data were collected for 20 revolutions of the OWIF, which was precisely timed using a stopwatch. Each of the 33 records showed a simple sinusoidal pattern but at different frequencies and amplitudes. Applying standard techniques of harmonic analysis to the data for the precisely known period, amplitude of each record was computed. These are given in Fig. 9. The right panel of the figure gives difference of angular rate from true. In both panels, the results from the three orientations were averaged and then a best fit, second order curve fit through the average values. We see that a small correction should be applied to field data, and that pre-calibration should be accomplished prior to deployment.

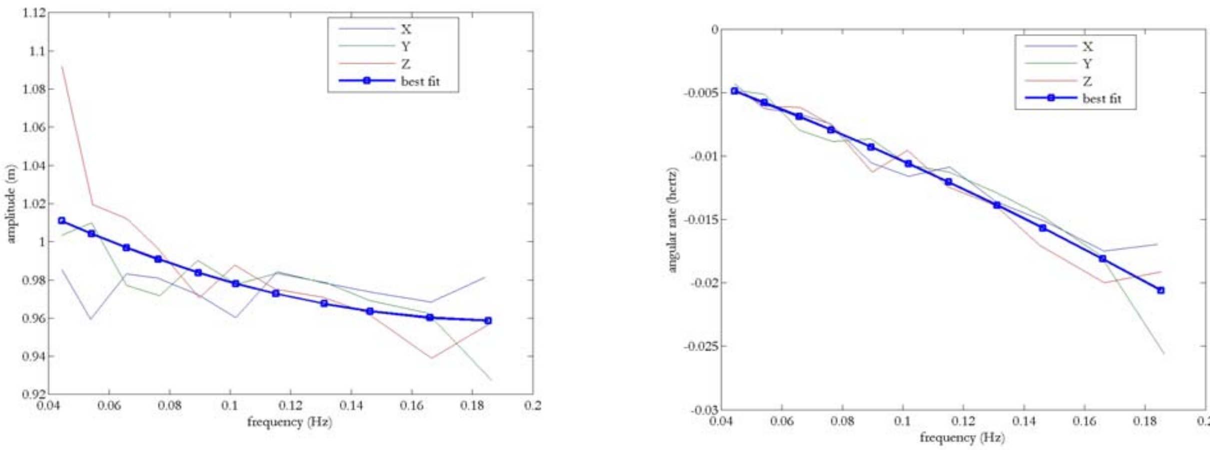

Fig. 9 Frequency-dependent response function from 3DM-GX1 for acceleration (left) and angular rate (right)

VIII. CONCLUSIONS

Careful testing of 3DM-GX1 sensor and WAMDAS processor has been conducted to ready the NDBC 1.8-m directional wave buoy for operational use in Cook Inlet. We have tested the 3DM-GX1 in the laboratory as well as on the desktop wave simulator. The wave processor was end-to-end tested using the OWIF and at sea. Moreover, the wave measuring capabilities of the complete 1.8-m system were rigorously tested using simultaneous measurements from the Datawell Waverider buoy, which is an accurate measuring device but less seaworthy than most NDBC wave buoys, enduring harsh marine conditions for years at a time. A weakness of the 1.8-m system is its inability to match the spectral sharpness of the particle-following Waverider. This deficiency results from the demand for greater buoy size, needed for long, unattended deployments. Larger hulls are not suitable for particle-following methods because of the mass of the hull and the need for a heavy mooring, which restricts horizontal motion. Continuing work on the 1.8-m wave measurement system will focus on hull-heave transfer and an improved low-frequency noise correction, which should give incremental improvement to the system. However, NDBC cannot expect the sensitivity of the Datawell Waverider unless it wishes to adopt a smaller, particle-following approach with light, elastic, compliant mooring. Testing, as documented in this paper, has proven the efficacy of the fundamental wave data processing methods and the value of the low-cost, small, lightweight MicroStrain 3DM-GX1.

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